

Comparative Evaluation of the Effectiveness of Erosion Control Materials



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Abstract: Over the past two years, a methodology for the equitable testing of surficial erosion control materials has been developed and tested using the portable University of Guelph rainfall simulator on highway construction slopes. This paper reports on the second year of work in which four hydraulic mulches and three erosion control blankets were tested. The results continue to confirm the validity of the original model based on the Universal Soil Loss Equation. The model is especially useful in categorizing equitably the effectiveness of surficial erosion control materials that vary widely in their composition, mode of operation, and effectiveness.

Because the results of the evaluation are in terms comparable to those used in the determination of the susceptibility of slopes to erosion, the categorization of erosion control materials/products using this model has the other practical application of assisting highway designers in identifying the group of erosion control materials/products that has an equal erosion control capability for a particular erosion susceptibility application. This ability to "match" the erosion capability of products to a potential level of erosion susceptibility should realize a greater success in achieving cost-effective temporary surficial erosion control, and minimize the potential environmental damages associated with sediment generated during and immediately following construction.

Based on these results, the Ontario Ministry of Transportation (MTO) is developing a testing protocol to be followed by companies desiring to obtain approval of the Ministry for contractors to use their erosion control products.

Comments: Prepared for presentation at the International Erosion Control Association Annual Conference, February 1992. This paper includes additional analysis of the data contained in MAT-91-07.

Key Words: rainulator, soil erosion, erosion control blankets, erosion control mulches, testing, universal soil loss equation, USLE, rainfall simulation

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1/ Introduction

The fundamental principles for the control of surficial erosion relate to the reduction of rainfall energy at the soil surface, and the reduction of runoff through improved infiltration. In the field of agriculture, much applied research has been conducted to develop and test cropping, residue, and water management erosion control strategies. In urban settings and transportation/utility corridors, a wide variety of rather different natural and synthetic mulches, barriers, blankets, and structures is available for soil erosion control. However, little is known of the effectiveness of a particular product in comparison to another under identical conditions, since a satisfactory testing and evaluation methodology has not been available. The ability to measure and evaluate the effectiveness of erosion control materials is needed especially since they are often so diverse in their makeup.

Historically, the effectiveness of soil erosion control mechanisms has been evaluated in two manners. Firstly, natural rainfall events were used to measure the level of soil erosion control achieved by different remedial measures. These studies were limited because they were difficult to replicate for a wide variety of rainfall intensities. Also, in order to obtain statistically reliable data, the studies had to be conducted for many years, at great expense. Secondly, rainfall simulators have been used to evaluate erosion control products in laboratory and field settings.

The use of the rainfall simulator facilitated the evaluation of products over a wide range of rainfall intensities. However, its use in the laboratory was complicated by difficulties in achieving soil conditions analogous to field conditions. Similarly, the use of the rainfall simulator under field conditions was hampered by equipment that was not sufficiently portable to allow a large number of replicated observations to be obtained at justifiable cost.

Recently, researchers at the School of Engineering and the Land Resource Research Centre at the University of Guelph developed and calibrated a relatively portable rainfall simulator for use in field studies of soil erosion and sedimentation processes (Tossell *et al*, 1987). In subsequent papers, the same authors published data on the comparison of the simulated rainfall properties to the properties of natural rainfall (Tossell *et al*, 1990). The simulator can produce rainfall intensities ranging from 17.5 mm/h to in excess of 200 mm/h by employing several low to medium-flow rate, full jet nozzles in a continuous spray design.

Results from the experimental field testing of two surficial erosion control products using this rainfall simulator on highway construction slopes (Armstrong and Wall, 1990) demonstrated the usefulness of this equipment for these studies. The results also verified the hypothesis that the rainfall (EI) value,

at which there was a significant change in the value of VM, or the Soil Loss Ratio (SLR), represented the point of the breakdown of the effectiveness of the material and the upper limit of the erosion control capability of the test material. The work also showed that erosion control materials/products could be evaluated equitably by a comparison of the rates of soil loss at breakdown. The results suggested that, in order to effect the optimum erosion control on a site, the erosion control capability of materials/products should be matched to the erosion susceptibility of the highway slope for the specified rainfall event or EI severity.

The present work, conducted during the summer of 1990, expands on these findings by testing seven erosion control products (3 blankets and 4 hydraulic mulches). This study has been developed to meet the following objectives:

- a) to evaluate and rank the quantitative effectiveness of seven erosion control products,
- b) to establish the range of rainfall energies over which these erosion control products remain effective.

2/ Study Approach

The study approach employed was developed previously by Armstrong and Wall (1990). It uses simulated rainfall to evaluate the effectiveness of seven erosion control products installed to MTO specifications on highway construction sites.

3/ Methods

3.1/ Study Sites

Several highway construction sites in Ontario were visited to locate soil and slope conditions suitable for study. Suitable site conditions included relatively erodible soils, 2:1 slope gradients, and slopes graded and top dressed to MTO specifications. Two sites were found to test four erosion control mulches, and one site was located to test three erosion control blankets. All erosion control products were installed to MTO specifications.

3.2/ On-Site Procedure

Runoff and erosion plots (1 m²) were established adjacent to each other on the 2:1 slope where the erosion control products had been applied. The plots had been established on bare soils and also on soils where the hydraulic mulches and erosion control blankets had been installed. Each plot consisted of a three-sided metal boundary with the open side in the downslope position. A metal lip and trough were installed at the open end to stabilize the soil at the lower boundary and collect runoff (Armstrong and Wall, 1990).

Simulated rainfall was applied to each plot at an intensity of 2.67 mm/min for a duration of 30 minutes (Tossell et al, 1987). Runoff volumes were recorded and sampled at 2-minute intervals for the duration of the experiment. Approximately 100 ml subsamples of runoff were obtained in duplicate for laboratory determination of sediment content.

Surface soil samples (0-20 cm) were collected from sites adjacent to runoff plots for laboratory soil characterization. Immediately prior to runoff experiments, surface soil samples (0-5 cm) were collected in duplicate to measure antecedent soil moisture.

3.3/ Laboratory Procedures

Soil samples were analyzed for particle size distribution, organic matter content, pH, and calcium carbonate content according to methods described by McKeague (1978). Soil moisture content was determined gravimetrically.

Sediment concentrations in runoff were determined gravimetrically in duplicate by filtering runoff through pre-weighed 0.45 µm filters under vacuum pressures.

The amount of protection afforded to the soil by a particular treatment is indicated by the Soil Loss Ratio (SLR) or VM factor. This factor is a ratio of the amount of soil loss under a particular treatment to the amount of soil loss on the same site under bare soil conditions. SLR/VM factors were calculated at various intervals during the rainfall simulations for the blanket and mulch treatments after methods described by Wischmeier and Smith (1978) and Clyde (1976).

3.4/ Statistical Analyses

Comparisons of runoff, soil loss, and sediment concentrations were made among the treatments. Analysis of variance (ANOVA) was performed, utilizing the SAS procedures (SAS Inst. Inc., 1985) to

determine whether or not significant differences ($P = 0.05$) existed between the various treatments and replicates. Duncan's Multiple Range Test was used to identify the treatments which differed significantly.

4/ Results

The evaluation of the erosion control products was conducted at three separate locations. Three of the hydraulic mulches (M_3 , M_4 , and M_5) were studied on fill-slope material, adjacent to a recently constructed overpass at the future Highway #407 and #427 interchange northwest of Toronto. Mulch P2 was studied on cut slope material in Albion Township, north of Highway 9 on the townline. The data presented for M_1 are taken from studies conducted in 1989 and reported by Armstrong and Wall [1]. The erosion control blankets (B_1 , B_2 , and B_3) were evaluated on cut slope material in Waterloo on Highway 86, just north of Northfield Drive.

Soil characterization at the study locations at Toronto, Albion Hills and Waterloo is reported in Table 1. The erosion control mulches were studied at the Toronto and Albion Hills sites where the soils ranged from clay loam to loam textures. Soil erodibility values were approximately 0.19 and 0.43, respectively. The severe erodibility potential for the Albion Hills site is attributed to the high silt and very fine sand content (>60%), and the low (<1%) organic matter content.

The erosion control blankets were studied on loam textured cut slope materials in Waterloo. The erosion potential for these sites was computed to be moderately severe ($K = 0.33$). These loam textured soils are less erodible than the loam textured soils at Albion Hills due to greater organic matter content and lower silt plus very fine sand content. At each study location, the control site exhibited the same general soil characteristics as the test sites. Recent rainfall resulted in each soil being at or near field capacity prior to rainfall simulation.

Each study plot was subject to simulated rainfall for 30 minutes at an intensity of 2.67 mm/min. Figure 1 illustrates the rainfall energy (EI) associated with different rainfall amounts delivered to the plots with time, as well as the probable return period of given amounts of rain within specific time periods. For example, the rainfall amounts occurring after 4, 6, and 10 minutes of simulation are equivalent to 5, 10, and 25 year return period storms. Similarly, the rainfall amounts occurring after 4, 10, and 20 minutes of rainfall are equivalent to storm energy (EI) values of 103, 412, and 1645 MJ mm/ha/h, respectively. For southern Ontario, the average EI value of approximately 1300 MJ mm/ha/h is reached in just less than 20 minutes.

5/ Soil Loss

5.1/ Erosion Control Mulches

Each of the erosion control mulches resulted in a reduction in soil loss compared to the control (Figure 2). Soil loss from the control plots approached approximately 2000 g in the case of M₂, while soil loss from the plots containing M₃, M₄, and M₅ was less than 1000 g by the end of the rainfall event. M₂ reduced soil loss relative to the control plot by >90% for the entire rainfall event, while M₃ reduced soil loss by >80% for much of the rainfall event. The other two mulches reduced soil loss by 60 - 70% and 30 - 40% for M₄ and M₅, respectively (Wall 1991). Statistical analysis of the data revealed differences between the mulch products and the control plots, but no statistical difference between the mulch products (Table 2).

5.2/ Erosion Control Blankets

Soil loss from the erosion control blanket plots and associated control plots are shown in Figure 3. The control plot lost approximately 8000 g of soil over the rainfall event. This soil loss level at the Waterloo site is approximately four times greater than the other control sites at Toronto and Albion Hills. However, soil loss from the erosion control blanket plots are all <1000 g for the rainfall event (Wall 1991).

Statistical analysis indicated that all of the erosion control blankets reduced soil loss significantly relative to the control. However, there were no significant differences between the blankets (Table 2).

6/ Erosion Control Effectiveness Evaluation

6.1/ Effectiveness Evaluation Rationale

The effectiveness of an erosion control material is given by the value of VM or the soil loss ratio (SLR) in the Universal Soil Loss Equation (USLE). The SLR is the ratio of the soil eroded from a treatment plot of known gradient, length, soil type and amount of rainfall compared to the amount of soil eroded from a bare control plot under otherwise identical conditions. In this experiment, the rainfall was provided by the rainfall simulator described previously.

When all parameters, except the rainfall factor, are kept constant and equal for the treatment and

control plots, and sediment and runoff from the plots are collected at constant and equal time periods, it is possible to measure the change in the effectiveness of the erosion control material on the treatment plot. This is done by plotting the amount of sediment generated from the treatment plot against the comparable amount of sediment generated from the control plot, over the same time period. Because the addition of rainfall provides cumulative erosion stress on the soils, erosion control material should provide evidence of failure by an increased ratio of sediment generated from the treatment plot in contrast to its companion control plot. As shown by Armstrong and Wall (1990), the progressive failure of an erosion control product is indicated by either a gradual ascending and curvilinear form, indicative of progressive failure, or an abrupt increase in the soil loss ratio, indicative of a sudden failure. The point in time during the rainfall simulation, when failure is identified, is used to determine the amount of rainfall kinetic energy (EI) applied to the material. Knowing the kinetic energy delivered by the rainfall simulator at any point in time, this value can be used in calculating the point of RKLS (failure) by employing the values for K, the soil erodibility index, and the length-slope (LS) index in the USLE. This product then becomes an index of the capability of the erosion control material to meet the stresses imposed by all the factors involved on surficial erosion.

6.2/ Erosion Control Mulches

Figure 4 shows three such plots of this index for M₃, M₄, and M₅ of the Toronto location. This figure also shows the points for each of the mulches where there appeared to be a significant deviation of a datum from linearity. For M₃, M₄, and M₅, these points of apparent failure occurred at 9, 7, and 5 minutes, respectively. These points represent EI values of 400, 300, and 200 based on the plot of rainfall energy (EI) for the University of Guelph's rainulator which was used in the study and is shown in Figure 1.

A similar analysis for M₂ is shown in Figure 5. This figure shows a straight line relationship, for the entire thirty minutes of the test, on soil with a measured soil erodibility of $K = 0.46$. A closer comparison of the amount of sediment generated on the control plots, relative to those plots that were used for the other mulch tests and which were situated on much less erodible soils, makes it obvious that these observations are misleading and cannot be used to identify the point of failure of this product.

The results of the 1989 testing of M₁ and B₂ were reported by Wall and Armstrong (1990) (Figure 7). This mulch was not tested in the present study and is included here since the testing procedures were the same. The point of breakdown of this mulch occurred at 9 minutes, corresponding to an EI value of 400. The corresponding values for RKLS are also presented.

The relative effectiveness of these five mulches for erosion control in descending order is M₁, M₂, M₃, M₄ and M₅.

6.3/ Erosion Control Blankets

The plots of the cumulative soil loss on the treatment plots, against the cumulative soil loss on the bare soil plots for B₁, B₂ and B₃ is shown in Figure 6. While the plot for B₂ exhibits a relatively constant straight line for the thirty minute test period, the plots for B₁ and B₃ illustrate an ascending curvilinear relationship, roughly comparable in appearance to the shape of the plot for the three mulches in Figure 4.

The points of failure for B₁ and B₃ are 9 and 10 minutes, representing values of approximately 450 and 500, respectively. The comparable EI value for B₂ is 3708, being the maximum value for EI that the University of Guelph's rainulator could deliver during these test runs. This EI value is justified for this blanket since there is no evidence of failure throughout the test.

The results from the 1989 study, previously reported by Armstrong and Wall (1990), are shown in Figure 7. The blanket in the 1990 study is the same as that used in the present study. This blanket exhibited comparable results to those shown in the present study with an EI value of 3708 (Figure 6).

6.4/ Comparative Evaluation

Figure 8 show the comparison of the blankets and mulches described by Armstrong and Wall (1990) and those presented in terms of RKLS values in this study. The maximum value of RKLS is 13 000, derived by using a very high value of 0.50 for K, an LS value of 20 corresponding to a cut or fill 12 m high on a 2:1 gradient, and a value for R of 1300, representing the average annual rainfall energy (EI) for Ontario (Armstrong and Wall, 1990). This gives a maximum index value of 13 000 and further represents the maximum average annual erosion susceptibility for Ontario.

The mulches and blankets appear to fall into two major groups based on their capability to withstand erosion forces. The delineating boundary is an RKLS value of approximately 3200. Only B₂ fell above this category, with the exception of M₂ which was previously excluded from this analysis. In relative sense, few of the mulches and blankets were very effective in showing any capabilities in handling the higher erosion susceptibilities.

7/ Discussion

The evaluation approach described is the only one known to these authors where very different erosion control products have been tested using an evaluation model that allows comparisons of materials on the same basis. In the Ontario Ministry of Transportation, the availability of such an evaluation approach is a vast improvement over the subjective evaluation of erosion control materials that has been used for years.

Of equal importance is the ability afforded to highway designers to estimate the erosion susceptibility of their proposed highway cuts and fills using the USLE, and then specifying the contract so that a category of equally effective erosion control measures is identified for the contractor to use as directed. This ability is also very important to the environmental designers and planners who are attempting to minimize potential environmental impacts associated with the construction of modern highway facilities.

In determining the erosion susceptibility of a cut or slope, the designer requires the following information:

- Average K values of the soils of the slopes on the project. These are determined in the laboratory after methods described by Weischmeier [19]. Table 3 can also be used.
- The height of the cut or fills. With this information and Figure 9, the designer can quickly determine the value of LS for any highway cut or fill to be designed and built to MTO standards.
- The location of the project in Ontario (Figure 10). With this information, the designer can estimate the average annual value of R, the Rainfall Factor. With modifications, this figure could also be made to represent the R value for any frequency combination of storm events on an annual basis.
- An estimation of the period in the year and the number of months over which construction is expected to occur. This information will allow the designer to estimate the probable time of application of the erosion control materials, and also the percentage of the annual rainfall likely to fall during the critical period of time (usually 30 days) it takes to establish an erosion resistant stand of vegetation.

With knowledge of the erosion susceptibility of the site, it is only necessary to identify the category of

erosion control materials/products which have the capability of resisting the erosion forces represented by the susceptibility values.

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Table 1/ Soil characterization of the study locations

Toronto

Plot	Depth (cm)	Texture	Gr	VCS %	CS by	MS weight	FS	VFS	Total S	SI	C	pH CaCl	CaCO %	Organic Matter %	"K" Value
Control	0-20	day loam	0	1.0	1.8	3.5	10.4	16.0	32.7	38.5	28.8	7.1	1.1	3.5	0.22
M ₃	0-20	day loam	0	1.0	1.5	3.5	11.5	16.1	33.6	37.5	28.9	7.1	2.1	3.7	0.18
M ₄	0-20	day loam	0	0.9	1.9	4.1	10.5	14.4	31.8	36.8	31.4	7.1	3.6	3.7	0.19
M ₅	0-20	day loam	0	2.5	3.6	5.3	10.8	13.8	36.0	35.0	29.0	7.2	5.4	3.2	0.19

Albion Hills

Plot	Depth (cm)	Texture	Gr	VCS %	CS by	MS weight	FS	VFS	Total S	SI	C	pH CaCl	CaCO %	Organic Matter %	"K" Value
Control	0-20	loam	2.9	1.3	1.1	2.0	9.4	15.2	29.0	47.6	23.4	7.4	30.9	0.2	0.40
M ₂	0-20	loam	2.8	2.2	1.6	2.4	13.1	24.1	43.4	42.3	14.2	7.3	27.4	0.5	0.46

Waterloo

Plot	Depth (cm)	Texture	Gr	VCS %	CS by	MS weight	FS	VFS	Total S	SI	C	pH CaCl	CaCO %	Organic Matter %	"K" Value
Control	0-20	loam	4.7	2.6	4.1	9.2	13.4	16.8	46.8	41.4	12.4	7.1	8.7	2.6	0.34
B ₁	0-20	loam	4.7	3.7	3.9	8.9	13.3	16.3	46.0	41.2	12.7	7.1	8.8	2.7	0.32
B ₂	0-20	loam	5.0	2.1	3.8	8.1	12.7	17.6	44.3	43.1	12.7	7.1	7.1	2.7	0.34
B ₃	0-20	loam	4.3	2.1	4.5	10.5	14.4	16.7	48.2	40.0	11.8	7.2	10.2	2.3	0.33

Table 2/ Statistical analysis of runoff, sediment concentration, and soil loss data (ANOVA and Duncan's Multiple Range Tests)

Erosion Control Mulch Products				
Return Period (years)	Soil Loss			
	Control	Mulch		
		M₃	M₄	M₅
5	A	B	B	B
10	A	B	B	B
25	A	B	B	B
50	A	B	B	B
100	A	B	B	B
200	A	C	BC	B
250+	A	C	BC	B

Return Period (years)	Control	M₂
5	A	B
10	A	B
25	A	B
50	A	B
100	A	B
250+	A	B

Erosion Control Blanket Products				
Return Period (years)	Soil Loss			
	Control	Blanket		
		B₂	B₁	B₃
5	A	A	A	A
10	A	B	B	B
25	A	B	B	B
50	A	B	B	B
100	A	B	B	B
200	A	B	B	B
250+	A	B	B	B

Treatments with the same letters do not differ significantly ($p = 0.05$).

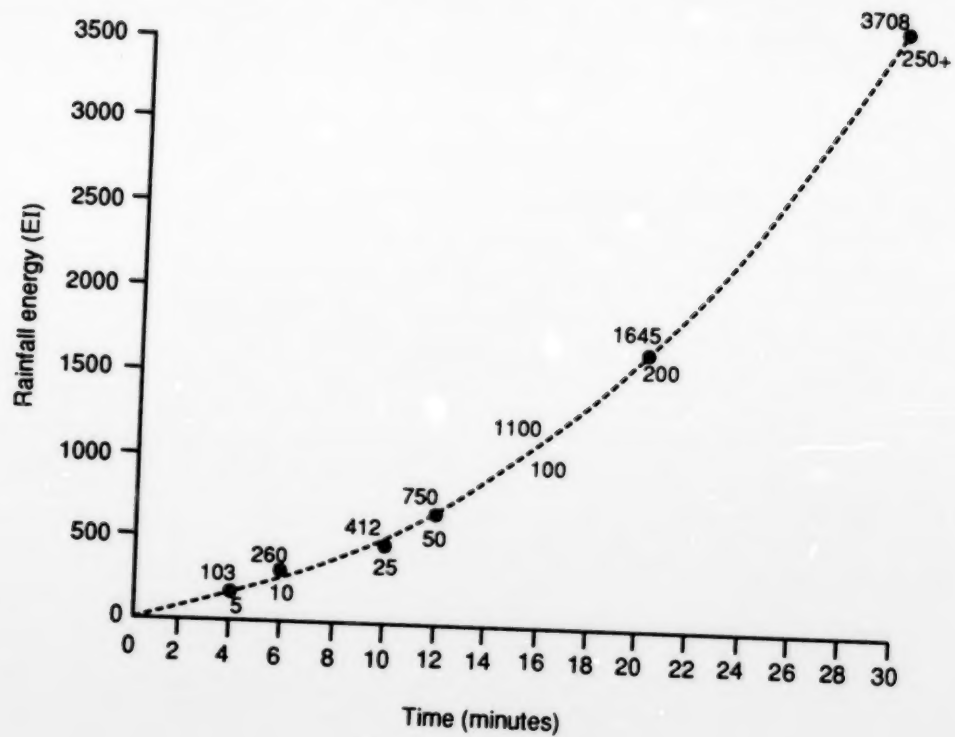


Figure 1/ Plot of rainfall energy (EI) and return period probability for the University of Guelph's rainulator

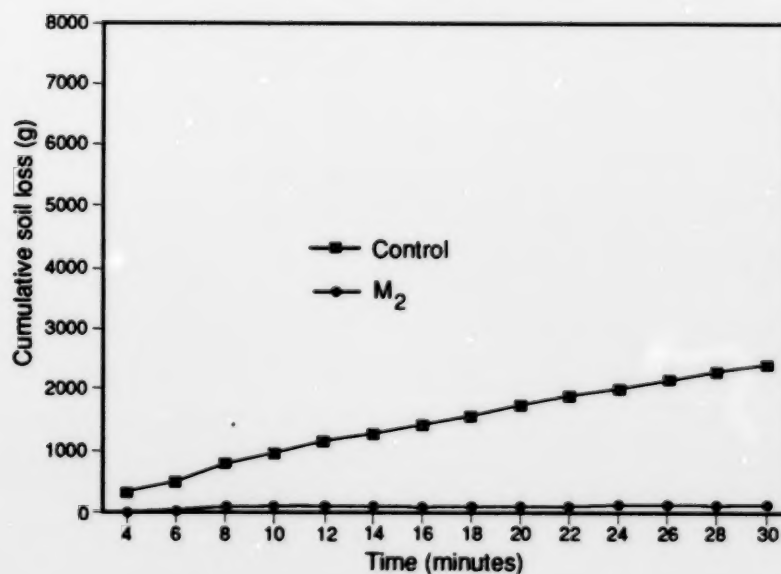
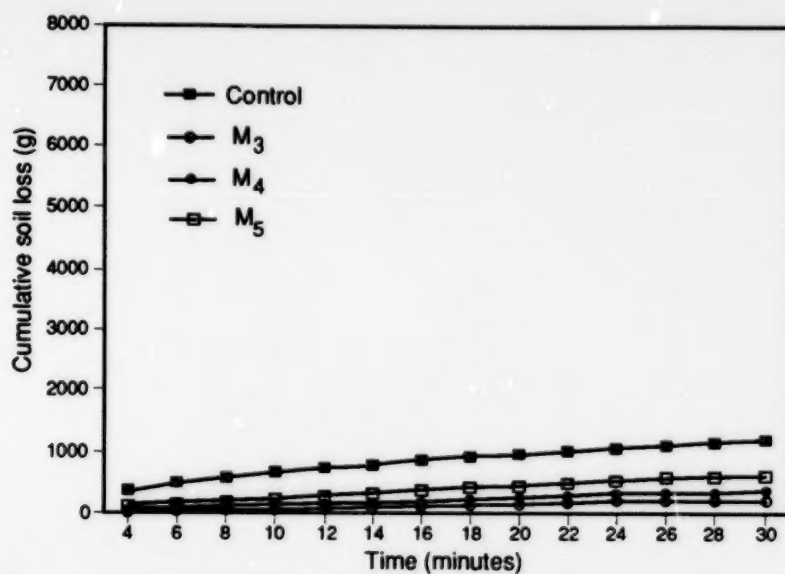


Figure 2/ Soil loss from erosion control mulch plots

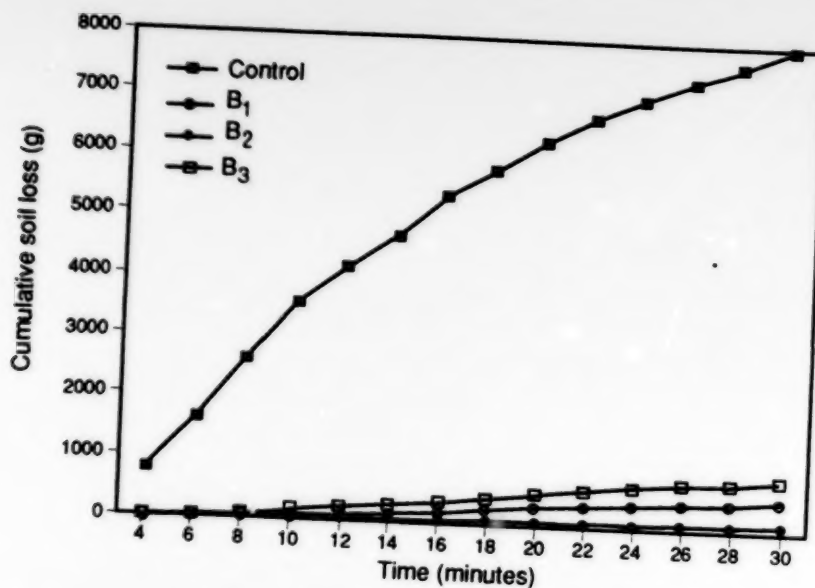


Figure 3/ Soil loss from erosion control blanket plots

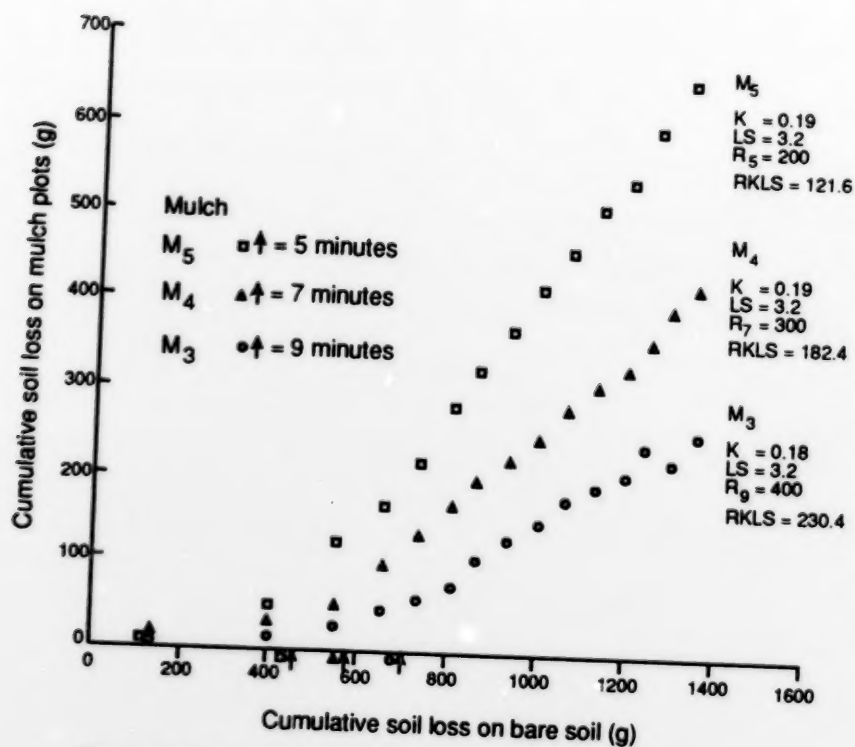


Figure 4/ Plot of cumulative soil loss for 3 mulches against cumulative soil loss on bare soil, 1990 data

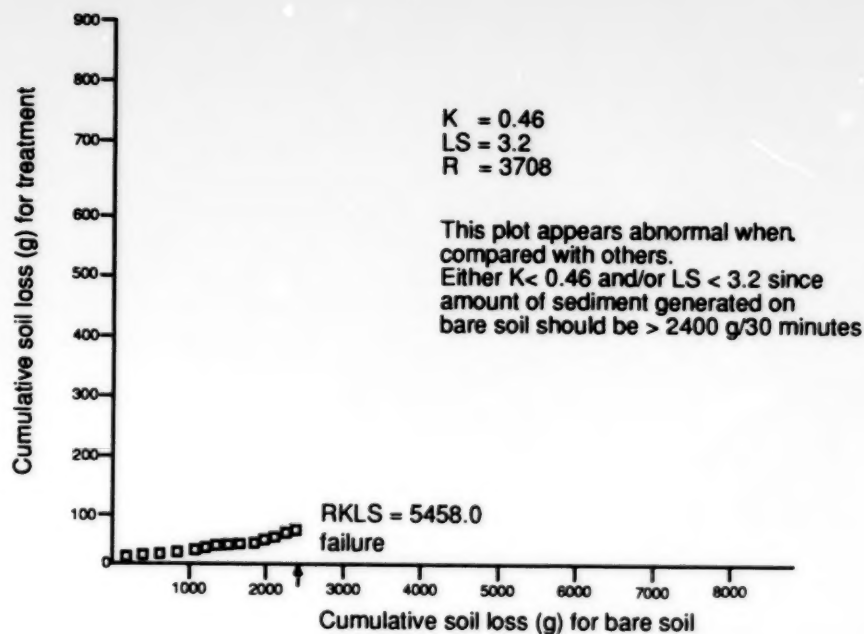


Figure 5/ Plot of cumulative soil loss on control plot against cumulative soil loss for M_2 , Nov. 1990 Data

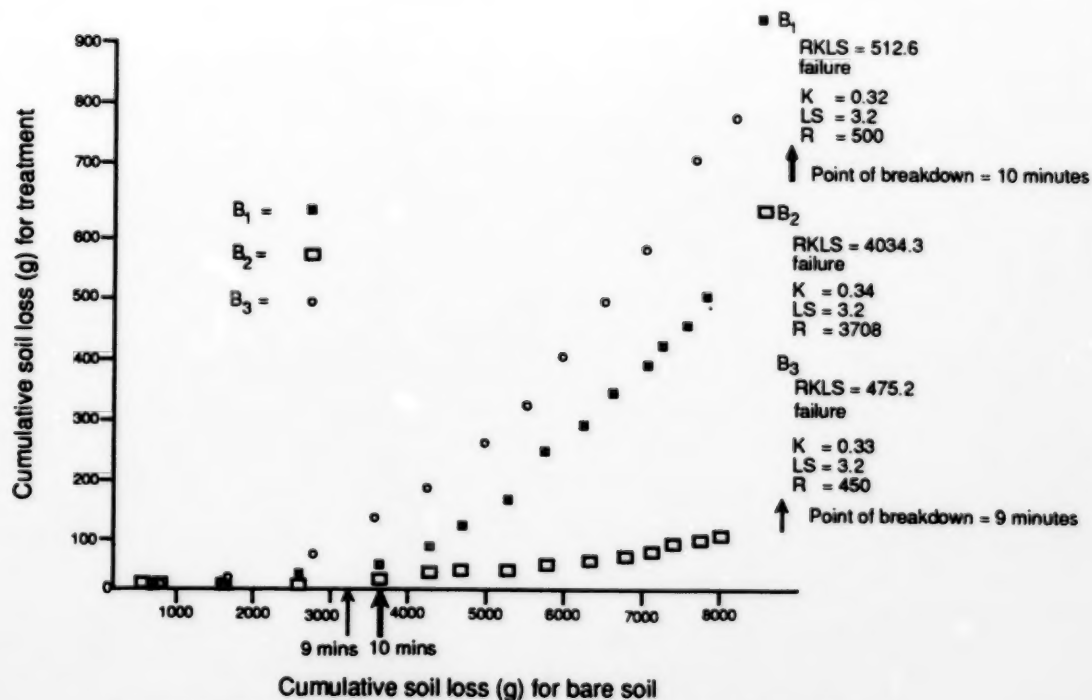


Figure 6/ Plot of cumulative soil loss on control plot against cumulative soil loss for B_1 , B_2 and B_3 1990 Data

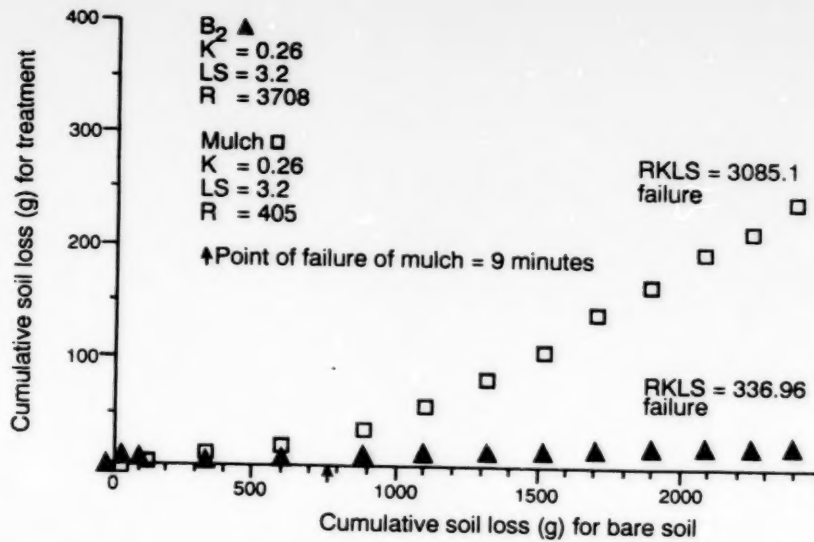


Figure 7/ Cumulative soil loss on mulch plots and blanket plots against cumulative soil loss on bare soils, 1989 Data

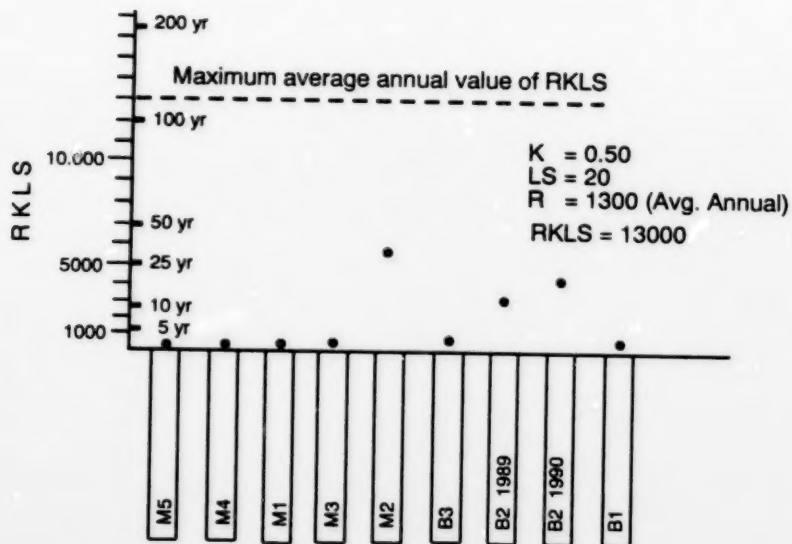


Figure 8/ Relative erosion control capability of mulches and blankets compared to maximum average erosion susceptibility

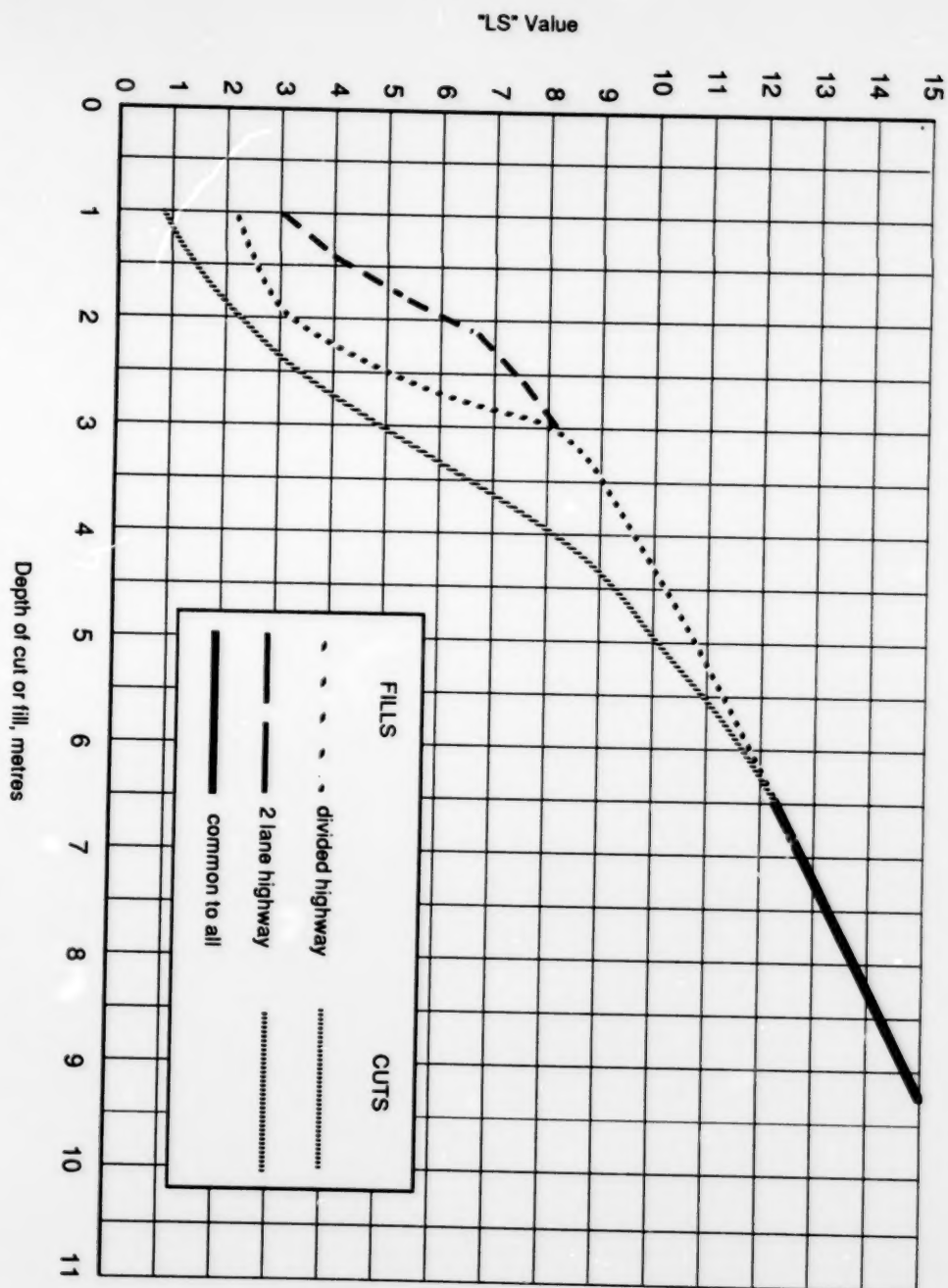


Figure 9/ Depth of cut or fill vs "LS" for Ontario highways

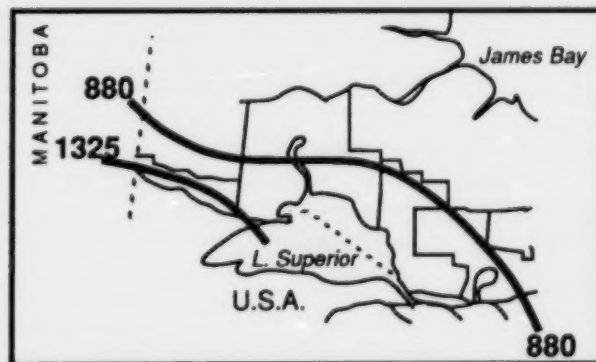
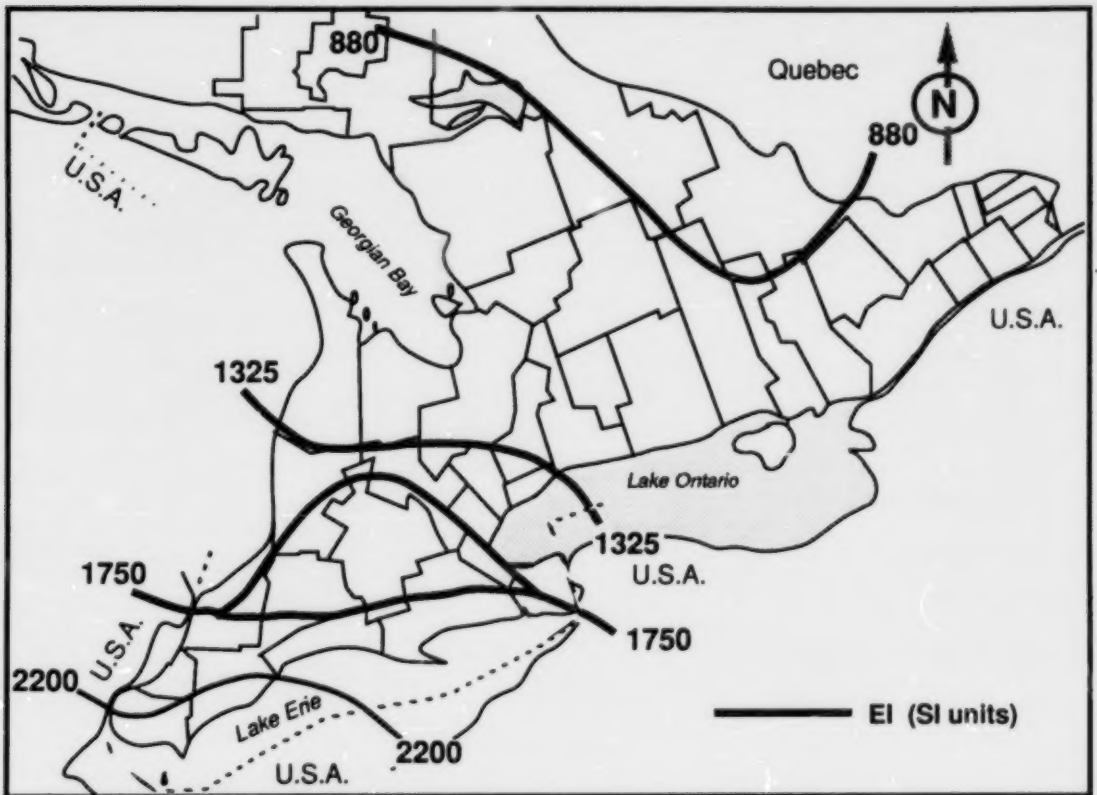


Figure 10/ Isoerodent EI (SI units) values for Ontario

Table 3/ Relationships between soil texture, OM, soil texture with soil erodibility (K), and sediment yield

Soil Texture	Organic Content					
	Under 0.5%		0.5% to 2%		2.1% to 4%	
	K	Sediment Yield	K	Sediment Yield	K	Sediment Yield
Sand	0.05	L	0.03	L	0.02	L
Fine sand	0.16	L	0.14	L	0.10	L
Very fine sand	0.42	H	0.36	M	0.28	M
Loamy sand	0.12	L	0.10	L	0.08	L
Loamy fine sand	0.24	M	0.20	M	0.16	L
Loamy very fine sand	0.44	H	0.38	M	0.30	M
Sandy loam	0.27	M	0.24	M	0.19	L
Fine sandy loam	0.35	M	0.30	M	0.24	M
Very fine sandy loam	0.47	H	0.41	H	0.33	M
Loam	0.38	M	0.34	M	0.29	M
Silt loam	0.48	H	0.42	H	0.33	M
Silt	0.60	H	0.52	H	0.42	H
Sandy clay loam	0.27	M	0.25	M	0.21	M
Clay loam	0.28	M	0.25	M	0.21	M
Silty clay loam	0.37	M	0.32	M	0.26	M
Sandy clay	0.14	L	0.13	L	0.12	L
Silty clay	0.25	M	0.23	M	0.19	L
Clay	0.13 - 0.2 (L to M)					